

# THE ABSOLUTE MAGNITUDE OF FIELD METAL-POOR HORIZONTAL BRANCH STARS <sup>★</sup>

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## ABSTRACT

HIPPARCOS satellite parallaxes for 22 metal-poor field horizontal branch stars with  $V_0 < 9$  are used to derive their absolute magnitude. The weighted mean value is  $M_V = +0.69 \pm 0.10$  for an average metallicity of  $[\text{Fe}/\text{H}] = -1.41$ ; a somewhat brighter average magnitude of  $M_V = +0.60 \pm 0.12$  for an average metallicity of  $[\text{Fe}/\text{H}] = -1.51$  is obtained eliminating HD17072, that might be on the first ascent of the giant branch rather than on the horizontal branch. The present values agree with determinations based on proper motions and application of the Baade-Wesselink method to field RR Lyraes; they are from 0.1 to 0.2 mag fainter than those based on calibration of cluster distances obtained by using local subdwarfs, and on alternative distance calibrators for the LMC. The possibility that there is a real difference between the luminosity of the horizontal branch for clusters and the field is briefly commented.

**Key words:** Clusters: globulars – Cosmology – Stars: basic parameters – Stars: stellar models

## 1 INTRODUCTION

The determination of the correct distance scale for metal-poor objects has a large impact on a wide range of astrophysical problems, including the derivation of ages of globular clusters (a stringent lower limit to the age of the Universe), of the extragalactic distance scale (affecting the determination of the Hubble constant), as well as important test on stellar evolution models. A long-standing lively debate divides the astronomical community amongst supporters of a “short” and a “long” distance scale: adoption of either of these two scales would have a deep influence on models for the universe, or for the formation of our own Galaxy (see e.g. Sandage 1993).

The recent distribution of the catalogue of calibrated trigonometric parallaxes measured by the HIPPARCOS satellite (Perryman et al. 1997) has provided new opportunities for accurate estimates of this distance scale. Various authors (Reid 1997; Gratton et al. 1997b; Pont et al. 1997) have used parallaxes of nearby subdwarfs to calibrate the distances to globular clusters. Results obtained by these three papers are significantly different: this is because different reddening and metal abundance scales were adopted for subdwarfs, and different corrections were applied to the original values in order to take into account for the presence of undetected binaries. Undirect estimates of the distances

to metal-poor objects have been obtained by considering the LMC distances based on Cepheids, on turn calibrated against nearby objects (Feast & Catchpole 1997).

An alternative way to use HIPPARCOS parallaxes is to consider horizontal branch (HB) stars, a traditional distance ladder for metal-poor population. Fernley et al. (1997) tried to measure directly the distances to RR Lyrae variables: however only the prototype of this important class of pulsating stars is within 300 pc from the Sun, so that its parallax can be measured with some reliability.

In this paper we will use HIPPARCOS parallaxes for three RR Lyraes, for a sample of nine red HB stars, selected on the basis of Strömgren photometry colours, and for ten field blue HB branch stars. Consideration of these other stars substantially enlarge the sample of nearby metal-poor HB stars. The sample is presented in Section 2; in Section 3 we discuss the derivation of the absolute magnitudes; finally the impact of the present results is briefly discussed in Section 4.

## 2 THE HORIZONTAL BRANCH SAMPLE

### 2.1 The red horizontal branch stars

The candidates field red horizontal branch (RHB) stars have been identified on the basis of the reddening corrected  $c_1$ ,  $b - y$  diagram published by Anthony-Twarog & Twarog (1994: see their Figure 8). Stars belonging to the red HB are

<sup>★</sup> Based on data from the ESA Hipparcos astrometry satellite.

clearly identified in this diagram as metal-poor stars with  $0.28 < (b - y)_0 < 0.46$  and  $c_0 \sim -1.815(b - y)_0 + 1.26$ . In order to enlarge the original sample of five stars with  $V < 9$  in the list of Anthony-Twarog & Twarog, we considered all stars listed in the homogeneized catalogue of Strömgren photometry (Hauck & Mermilliod 1990) occupying a similar position in the  $c_1, b - y$  diagram (we also considered the catalogues by Olsen 1993, 1994a, 1994b, but they did not provide additional good candidates). The selection criteria were  $V < 9$ ,  $0.2 < (b - y) < 0.5$ ,  $0.4 < c_1 < 0.8$ ,  $m_1 < 0.15$ , and  $-0.1 < [c_1 + 2(b - y) - 1.2] < 0.2$ . 86 stars passed these selection criteria: most of them are highly reddened A and F dwarfs. However, only ten stars have proper motion  $> 0.065$  mas/yr from the Hipparcos catalogue (corresponding to a transverse velocity  $> 130$  km s $^{-1}$  for  $V = 9$  and  $> 80$  km s $^{-1}$  for  $V = 8$  HB stars): with the exception of HD165908 (a dwarf at about 16 pc from the Sun, projected toward a direction very close to that of the galactic centre), all other high proper motion stars selected by this procedure are very good candidate RHB stars. Note that all the RHB stars listed by Anthony-Twarog & Twarog were recovered by this procedure. Basic data are given in Table 1.

The interstellar reddening and metallicity were obtained following the same procedure adopted by Anthony-Twarog & Twarog (1994, ATT). In order to compare the results obtained in this paper with other estimates for the absolute magnitude of the HB, we put the metal abundances listed by Anthony-Twarog & Twarog on the same system as those considered in Gratton et al. (1997b). To this purpose, we considered all stars in the original sample of Anthony-Twarog & Twarog which have metallicities measured by Gratton, Carretta & Castelli (1997a, GCC). We found that the mean relation between the two values of metallicity is:

$$[\text{Fe}/\text{H}]_{\text{GCC}} = (1.33 \pm 0.23)[\text{Fe}/\text{H}]_{\text{ATT}} + (0.56 \pm 0.32). \quad (1)$$

The values listed in Table 1 have been obtained from the original values listed by Anthony-Twarog & Twarog after application of eq. (1).

## 2.2 RR Lyrae

The sample of RR Lyrae was taken from Preston, Schectman & Beers (1991): it includes the only three known RR Lyrae variables with an average dereddened  $V_0$  magnitude brighter than 9. Metallicity and reddening for RR Lyr were taken from Clementini et al. (1995); those for RZ Cep and MT Tel were taken from Preston et al. (the  $\Delta S$  calibration of Clementini et al. was used). For RR Lyrae we assumed an average  $V$  magnitude of  $V = 7.66 \pm 0.05$  (Layden 1994); the rather large uncertainty is due to the Blazhko effect that is important for this star (note however that this uncertainty is much smaller than the error bar due to the parallax). For the two other stars we used the  $V_0$  values of Preston et al.

## 2.3 The blue horizontal branch stars

The blue horizontal branch (BHB) stars considered in this paper are taken from the list of Stetson (1991). Again, only stars with  $V < 9$  were considered. We found 12 such stars in the list of Stetson; parallax is not available for one of them (HD203653). According to Hipparcos, HD214539 has

a moderate proper motion of  $\mu = 0.036$  arcsec/yr, all other metal-poor HB stars considered in this paper having  $\mu > 0.065$  arcsec/yr; it also has a small value of the Strömgren  $c_1$  index of  $c_1 = 1.036$ , not compatible with its positive  $b - y$  colour if this star is on the HB. These two facts suggest that this star is not a BHB star; we finally decide to leave this star out from our sample.

We tried to enlarge this sample by considering all stars in the catalogue of homogeneized Strömgren photometry (Hauck & Mermilliod 1990) having colors similar to those of known BHB; however no additional star with proper motion larger than  $\mu = 0.05$  arcsec/yr was found. We then finally considered ten BHB stars.

Main parameters are listed in Table 1.  $V$  magnitudes are the average of those listed in the Hipparcos catalogue and those by Stetson (1991);  $B - V$  colours were taken from the Hipparcos catalogue, while Strömgren photometry was from Stetson (1991). Whenever possible, reddenings are those listed by Gray, Corbally & Philip (1996). However, this was possible for only five of the programme stars. For the remaining objects, reddening was obtained by comparing the  $\beta$  index (from Stetson) with the apparent  $B - V$  colour, assuming that the following relation (obtained by considering stars with reddening from Gray et al.) holds for BHB stars:

$$\beta = 2.861 + 0.188(B - V)_0 - 6.581(B - V)_0^2. \quad (2)$$

For some objects there is ambiguity on the reddening determined by this procedure, two values being compatible with data. We initially assumed the lowest reddening solution for all stars; however, we found that the higher reddening solution is required to explain the observations for HD93329 and HD139961. Our reddening estimates are very close to the values adopted by De Boer, Tucholke, & Schmidt (1997): the average difference for the five stars in common is  $0.005 \pm 0.008$  mag (single star standard deviation of 0.018 mag), in the sense that our reddenings are smaller.

Metallicities were taken from Adelman & Philip (1996). The metallicity scale for the BHB stars is quite uncertain, due to the possible effects of diffusion in the subatmospheric layers, and of departures from LTE in the photospheric regions. However, these effects are ignored in our discussion. For the two stars missing metal abundance values (HD31943 and HD139961), we assumed a metal abundance equal to the average provided by the other BHB stars ( $[\text{Fe}/\text{H}] = -1.66$ ).

## 2.4 Sample incompleteness

Our total sample consists of 20 field horizontal branch stars with  $V \leq 9$  (8 with  $V \leq 8$ , 2 with  $V \leq 7$ ), and two slightly fainter stars. We roughly estimate incompleteness of our sample by comparing these numbers with the list of metal poor dwarfs ( $[\text{Fe}/\text{H}] < -0.9$ ) compiled by Gratton et al. (1997c); this list provides an extensive though still incomplete census of metal poor dwarfs with  $V < 10.3$  and  $5 < M_V < 6.5$ . Within this sample of subdwarfs, we have 12 stars with  $5.0 < M_V < 5.5$  (closer than  $\sim 100$  pc from the Sun), 9 stars with  $5.5 < M_V < 6.0$  (closer than  $\sim 80$  pc), and 9 stars with  $6.0 < M_V < 6.5$  (closer than  $\sim 60$  pc). Assuming completeness down to  $V = 10.3$  (surely an upper limit), this yields a total of  $\sim 9,000$  main sequence stars with  $[\text{Fe}/\text{H}] < -0.9$  and  $5 < M_V < 6.5$  within 500 pc from

**Table 1.** Data for the HB sample

HD	$V$	$B - V$	$b - y$	$m_1$	$c_1$	$E(B - V)$	[Fe/H]	$\pi$	$M_v$	$\delta M_V$
Blue Horizontal Branch stars										
31943	8.254	0.121	0.083	0.142	1.226	0.015		$3.88 \pm 0.74$	$1.15 \pm 0.41$	-0.09
74721	8.710	0.042	0.029	0.127	1.273	0.000	-1.43	$0.34 \pm 1.46$	$-3.63 \pm 9.32$	-0.30
86986	8.000	0.119	0.092	0.109	1.278	0.035	-1.88	$3.78 \pm 0.95$	$0.78 \pm 0.55$	-0.13
93329	8.780	0.129	0.060	0.123	1.315	0.156	-1.39	$3.89 \pm 1.09$	$1.25 \pm 0.61$	-0.60
109995	7.605	0.047	0.050	0.117	1.305	0.001	-1.78	$4.92 \pm 0.89$	$1.06 \pm 0.39$	-0.28
128801	8.739	-0.038	-0.005	0.109	1.056	0.037	-1.17	$2.40 \pm 1.18$	$0.53 \pm 1.07$	-0.86
130095	8.134	0.032	0.064	0.108	1.256	0.064	-1.92	$5.91 \pm 1.08$	$1.79 \pm 0.40$	-0.62
139961	8.861	0.098	0.077	0.115	1.298	0.107		$4.50 \pm 1.19$	$1.80 \pm 0.57$	-0.52
161817	6.978	0.166	0.126	0.100	1.197	0.020	-1.69	$5.81 \pm 0.65$	$0.74 \pm 0.24$	-0.03
167105	8.960	0.020	0.036	0.120	1.260	0.057	-1.89	$3.02 \pm 1.78$	$1.18 \pm 1.28$	-0.64
RR Lyrae variables										
RR Lyr	7.66					0.03	-1.39	$4.38 \pm 0.59$	$0.77 \pm 0.29$	0.00
RZ Cep	9.57					0.35	-1.59	$0.22 \pm 1.09$	$-4.80 \pm 10.75$	0.00
MT Tel	9.10					0.045	-2.00	$1.01 \pm 1.26$	$-1.02 \pm 2.71$	0.00
Red Horizontal Branch stars										
17072	6.610	0.660	0.441	0.132	0.452	0.011	-0.77	$7.57 \pm 0.51$	$0.97 \pm 0.15$	-0.02
18550	8.260	0.455	0.29	0.12	0.74	0.004	-0.66	$3.35 \pm 1.06$	$0.87 \pm 0.69$	-0.01
25532	8.208	0.657	0.482	0.094	0.507	0.074	-1.08	$4.39 \pm 1.25$	$1.19 \pm 0.62$	-0.02
97650	7.880	0.653	0.45	0.14	0.43	-0.008	-0.98	$3.13 \pm 0.99$	$0.38 \pm 0.69$	-0.02
105546	8.610	0.660	0.460	0.130	0.420	0.000	-1.33	$1.96 \pm 0.91$	$0.07 \pm 1.01$	-0.02
106373	8.918	0.442	0.338	0.031	0.732	0.061	-2.74	$2.22 \pm 1.09$	$0.46 \pm 0.92$	0.00
107550	8.350	0.719	0.50	0.14	0.43	0.054	-0.78	$2.81 \pm 1.07$	$0.43 \pm 0.83$	-0.02
184266	7.600	0.548	0.427	0.063	0.605	0.054	-1.93	$3.28 \pm 0.95$	$0.01 \pm 0.63$	-0.01
208360	7.630	0.640	0.46	0.12	0.45	0.018	-1.17	$4.71 \pm 0.93$	$0.94 \pm 0.43$	-0.02

the Sun (where we assumed a uniform distribution and neglected interstellar absorption). The ratio between HB stars and main sequence stars in this luminosity range depends on the adopted slope of the initial mass function; it is  $\sim 120$  for a Salpeter value. Ignoring interstellar absorption and assuming a typical magnitude of  $V \sim 0.6$  for HB stars, we then expect to observe  $\sim 75$  metal-poor HB stars ( $\sim 20$  with  $V < 8$ , and  $\sim 5$  with  $V < 7$ ) within the limiting magnitude here considered ( $V < 9$ ,  $\sim 500$  pc). It must be noted that these numbers depend on our assumptions: a larger number of missing stars is expected due to uncompleteness of the subdwarf sample here considered; on the other side, galactic distribution of stars and interstellar reddening should reduce the expected number of metal-poor HB stars with  $V < 9$ . However, we will assume they represent a rough estimate of the real number of HB stars; they suggest that our sample includes about half of the HB stars with  $V < 8$ , and roughly 20% of those with  $8 < V < 9$ . Missing stars are more likely to be metal-rich (half of the present sample is made of stars with  $[\text{Fe}/\text{H}] < -1.5$ , while they are only a third of the comparison subdwarf sample) and/or to have moderate or low proper motion ( $\sim 1/3$  of the subdwarfs of the comparison sample have transverse velocities  $< 100 \text{ km s}^{-1}$ ). Strömgren photometry may also be missing for a considerable fraction of the field HB stars with  $V > 8$ .

### 3 MEAN ABSOLUTE MAGNITUDES

A basic problem in the derivation of mean absolute magnitudes when errors on parallaxes are similar to the measured values is to give the appropriate weight to individual stars. The usual procedure is to average absolute magnitude values with weights given according to the individual errors in the absolute magnitude: this is simply  $2.17 \Delta\pi/\pi$ , where  $\pi$  is the parallax and  $\Delta\pi$  its error. This procedure overestimates weights given to those objects having parallaxes measured too high (that is located closer than they really are) with respect to those objects having parallaxes measured too low (that is located farther than they really are). The net effect is that distances are underestimated, and hence on average the mean absolute magnitude is estimated to be fainter than really is. This is one of the causes of the so-called Lutz-Kelker effect (Lutz & Kelker 1973).

In order to give same weight to parallaxes measured too high and too low, we decided to average the parallaxes rather than the absolute magnitudes. In practice, we assumed that all stars have the same absolute magnitude  $M$ , apart from a term dependent on the colour  $\delta M(B-V)$  which accounts for the not perfect horizontality of the HB; this value was determined by interpolation on the mean loci of M5 (Sandquist et al. 1996), for which we assumed a reddening of  $E(B-V) = 0.035$  (Gratton et al. 1997b) and a magnitude of  $V = 15.11$  at centre of the RR Lyrae strip. M5 was selected because it has an extended HB and accurately

calibrated photometry available. It should however be noted that M5 ([Fe/H]=−1.17; Sneden et al., 1992; [Fe/H]=−1.11; Carretta & Gratton, 1997) is slightly more metal-rich than the bulk of the program HB stars ([Fe/H] ∼ −1.5). The expected value of the parallax  $\pi^*$  corresponding to this value of  $M$  is simply given by:

$$\pi^* = 10^{0.2 [M - V - \delta M(B - V)] - 1 + 0.62 E(B - V)}, \quad (3)$$

where  $V$  is the apparent magnitude and  $E(B - V)$  is the interstellar reddening. The value of  $M$  is then derived by assuming that the weighted average of  $\pi - \pi^*$  is zero.

Two other systematic corrections should in principle be applied to our sample:

- a fraction of the programme stars is expected to have a companion. The total magnitude of the system is then expected to be brighter than for single stars. This correction should be small, because it is unlikely that the companion is also an evolved star. To estimate this correction, we computed the average correction due to a secondary which has the same luminosity function (transformed from  $B$  to  $V$  magnitudes) of M5 observed by Sandquist et al. (1996). The average correction for a binary system made of an HB star and a secondary brighter than  $M_V \sim 7$  is estimated to be 0.019 mag. Only a fraction of the observed HB stars have such a bright companion. We then estimate that the binary correction for the whole sample is  $< 0.01$  mag. We will neglect this small correction

- star selection has a threshold in the apparent  $V$  magnitude ( $V < 9$ ). A Malmquist bias is then expected to be present, favouring intrinsically bright objects. The correction is expected to be quite small, because HB stars have a small intrinsic scatter in their absolute magnitudes (at a given metallicity, peak-to-peak dispersion is  $\leq 0.3$  mag). We estimated this correction by means of Monte Carlo simulations, assuming a uniform space distribution for HB stars (likely a good approximation for nearby objects). We found that Malmquist correction is  $\sim 0.01$  mag for a uniform distribution of  $M_V$ 's within a range of 0.3 mag, and  $\sim 0.02$  mag for a range of 0.4 mag (these results depend only very marginally on the adopted average  $M_V$ ). The actual distribution is likely to be more peaked than a uniform distribution, so that these estimates of the Malmquist bias are likely to be somewhat overestimated. Note also that this Malmquist bias is partly compensated by the selection criterion based on proper motion, favouring nearby intrinsically faint objects with respect to far brighter ones; this effect is however expected to be smaller than the Malmquist bias because it depends linearly rather than quadratically on distance. This is confirmed by Monte Carlo simulations which takes into account the kinematical properties of the metal-poor stars: we found that the correction for the proper motion threshold amounts to less than 0.005 mag for any reasonable value of the parameters. Hereinafter we will neglect these corrections, being much smaller than other sources of error

Using this procedure, the weighted average absolute magnitude of the HB at the RR Lyrae colour is:

$$M_V(RR) = 0.69 \pm 0.10. \quad (4)$$

The weighted mean metallicity of the stars used to derive this relation is [Fe/H]=−1.41.

**Table 2.** Average magnitude for field HB stars

bin	No. stars	[Fe/H]	$M_V(RR)$
[Fe/H] < −1.5	11	−1.84	$0.63 \pm 0.17$
−1.5 < [Fe/H] < −1.0	7	−1.31	$0.58 \pm 0.21$
[Fe/H] < −1.0	4	−0.79	$0.85 \pm 0.15$

It should be noted that  $\sim 30\%$  of the total weight in the present derivation of the absolute magnitude of the metal-poor HB stars is due to a single star, namely HD17072, for which we found  $M_V = 0.97 \pm 0.15$ . This is a rather metal-rich star ([Fe/H]=−0.77  $\pm$  0.3): misclassification of red giant branch stars as red HB stars is possible when the  $c_1$ ,  $b - y$  diagram is used for metal-rich objects. It is then possible that this star is on the red giant branch rather than on the HB. If this star is eliminated, the weighted average absolute magnitude would be:

$$M_V(RR) = 0.60 \pm 0.12 \quad (5)$$

for an average metallicity of [Fe/H]=−1.52. Given its moderately high metal abundance, the absolute magnitude of HD17072 is marginally consistent with the value estimated from the remaining stars, if a slope of  $\sim 0.2$  is adopted in the relation between absolute magnitude and metallicity for HB stars (see e.g. the discussion in Gratton et al. 1997b).

If we consider separately RHB, RR Lyrae variables and BHB stars, we found average magnitudes of:

$$M_V(RR) = 0.75 \pm 0.14 \quad (9 \text{ RHB stars}), \quad (6)$$

$$M_V(RR) = 0.33 \pm 0.31 \quad (3 \text{ RR Lyrae variables}), \quad (7)$$

and:

$$M_V(RR) = 0.73 \pm 0.16 \quad (10 \text{ BHB stars}) \quad (8)$$

for average metal abundances of [Fe/H]=−1.15, [Fe/H]=−1.52, and [Fe/H]=−1.66 respectively. The result for BHB stars is quite heavily influenced by the colour correction for the non-horizontality of the HB, which may be as large as 0.6 mag and it is quite uncertain. However, the average magnitude changes by only 0.02 mag (up to  $M_V(RR) = 0.71 \pm 0.19$ ) when only stars with  $(B - V)_0 > 0$  are considered. We conclude that our result is only marginally dependent on the colour correction for the non-horizontality of the HB.

The uncertainties present in this estimate for the average magnitude of the HB preclude an accurate estimate of the dependence of HB magnitude on metallicity. In fact, if we divide our sample into three groups according to metal abundance ([Fe/H] < −1.5, −1.5 < [Fe/H] < −1, and [Fe/H] > −1), we find the average magnitudes listed in Table 2; a weighted mean square fit through these three points then gives:

$$M_V(RR) = (0.22 \pm 0.22)([Fe/H] + 1.5) + (0.66 \pm 0.11). \quad (9)$$

The large error bar for the slope of this relation makes it compatible with all literature estimates.

## 4 DISCUSSION AND CONCLUSIONS

On the whole, estimates of the absolute magnitude of the HB for metal-poor stars provide contradictory results. Other de-

terminations from direct observation of field HB stars lead to values very close to that derived in this paper. Layden et al. (1996) obtained  $M_V(RR) = +0.71 \pm 0.12$  for  $[\text{Fe}/\text{H}] = -1.6$ , and  $M_V(RR) = +0.79 \pm 0.30$  for  $[\text{Fe}/\text{H}] = -0.76$  from (ground-based) statistical parallaxes of RR Lyrae stars. Similar faint magnitudes are obtained from application of the Baade-Wesselink method to RR Lyraes; for instance Clementini et al. (1995) obtained:

$$M_V(RR) = (0.19 \pm 0.03)([\text{Fe}/\text{H}] + 1.5) + (0.68 \pm 0.04). \quad (10)$$

Very similar relations were previously obtained by Carney, Storm & Jones (1992) and Fernley (1993); note however that brighter absolute magnitudes and a steeper slope has been recently obtained by McNamara (1997) from a reanalysis of Baade-Wesselink results using a higher temperature scale:

$$M_V(RR) = (0.29 \pm 0.05)([\text{Fe}/\text{H}] + 1.5) + (0.53 \pm 0.05). \quad (11)$$

The value for the slope of the  $[\text{Fe}/\text{H}] - M_V(RR)$  relation is lively debated (for a discussion, see e.g. Carney et al. 1992). As mentioned above, this slope cannot be determined from data of the present paper alone. However, if we arbitrarily adopt the slope given by Clementini et al. (1995), we found:

$$M_V(RR) = 0.19([\text{Fe}/\text{H}] + 1.5) + (0.66 \pm 0.10). \quad (12)$$

If we now consider the constant term, the agreement with the value from Clementini et al. (1995) is fully satisfactory (a marginal agreement is found also with the relation of McNamara). On the other side, if HD17072 is eliminated, the relation would be:

$$M_V(RR) = 0.19([\text{Fe}/\text{H}] + 1.5) + (0.61 \pm 0.12), \quad (13)$$

still in agreement with the value obtained using the Baade-Wesselink technique.

On the other hand, much brighter magnitudes are obtained by those estimates based on the HB of globular clusters. As an example, Gratton et al. (1997b) determined the magnitude of the HB from a calibration of globular cluster distances based on subdwarfs:

$$M_V(RR) = (0.22 \pm 0.09)([\text{Fe}/\text{H}] + 1.5) + (0.43 \pm 0.04), \quad (14)$$

where we consider eq. (11) of Gratton et al., that is more appropriate for a comparison with field HB stars because it takes into account the evolution of stars off the zero age horizontal branch (ZAHB). Very recently, Gratton et al. (1997c) revised this relation to the following:

$$M_V(RR) = (0.18 \pm 0.09)([\text{Fe}/\text{H}] + 1.5) + (0.47 \pm 0.04), \quad (15)$$

using a more extended sample which includes nearly 60 metal-poor subdwarfs with accurate parallaxes. The average magnitude of the HB obtained in the present paper is 0.19 mag fainter than the relation provided by the calibration of globular cluster distances based on subdwarfs. The disagreement is even worse if the distance scale found by Reid (1997) is considered; and it decreases only marginally if the distance scale considered by Pont et al. (1997) is adopted. Note however that the average magnitude we obtain eliminating HD17072 is in marginal agreement with that found using the calibration of globular cluster distances based on subdwarfs.

Another argument in favour of a *long* distance scale (longer than found here) is provided by consideration of the RR Lyrae in various clusters in the Large Magellanic

Cloud (LMC) (with an average  $[\text{Fe}/\text{H}] = -1.9$ ), whose distance is assumed to be identical to that of the LMC obtained from other calibrators. The first determination by Walker (1992) was  $M_V = 0.44$ , for an LMC true distance modulus of  $(M - m)_0 = 18.50$  based on pre-Hipparcos calibration of the period-luminosity relation for the Cepheids. The value has been recently revised to  $M_V = 0.24 \pm 0.10$  by Feast & Catchpole (1997) using a calibration of the Cepheid period-luminosity relation based on Hipparcos data. Less extreme, but still bright magnitudes are obtained using the LMC distance modulus from Hipparcos calibration for Miras ( $M_V = 0.40 \pm 0.2$ : van Leeuwen et al. 1997), and from the expanding ring around SN1987a ( $M_V = 0.36 \pm 0.03$ : Panagia et al. 1997; note however that a fainter value of  $M_V > 0.50$  has been obtained by Gould & Uza 1997). Even considering a  $\sim 0.08$  mag correction for the metallicity of the LMC clusters, these estimates are brighter than the present value for the constant term in eqts. (12) and (13), while they agree with the determination based on local subdwarfs and globular clusters (eqt. 15).

While a marginal agreement between the distance scale derived from parallax of field HB stars and those which use globular clusters can be found excluding HD17072, on the whole it seems that the distance scales provided by field stars are uncomfortably shorter than those provided by globular clusters. Is there something wrong in some of these distance derivations? An accurate revision of each method is beyond the scope of the present discussion; we only note that the present derivation is independent of stellar models, and it depends only marginally on the adopted reddening and abundance scales; it is however sensitive to the attribution of individual stars to the HB: this may be questioned for some important object. Furthermore, the error bar is quite large. On the other side, the calibration of the cluster distances using local subdwarfs may be critically affected by systematic errors in the metal abundance and reddening scales. For instance, it would be increased by  $\sim 0.08$  mag if the metallicity scale for globular clusters (derived from high dispersion spectroscopic analysis of giants) is systematically too large with respect to the scale adopted for subdwarfs (derived from analysis of dwarfs) by 0.1 dex. In both cases the real error bars are then larger than the nominal one, given by dispersion of individual data.

It might also be noted that there seems to be good agreement between different estimates for field HB stars; the same can be said for those estimates using globular cluster HB stars. This fact might suggest that there is perhaps a real difference between the magnitude of the HB between globular clusters and the general field, at the level of 0.1 or 0.2 mag. Theoretical arguments supporting such a difference have been recently advanced by Sweigart (1997), who considered the possibility that the Na-O and Mg-Al anti-correlations observed in globular cluster red giants, but not in field stars (Kraft 1994, and references therein), are due to mixing presumably related to internal rotation. In this scenario helium is also getting mixed, producing a markedly bluer and somewhat brighter HB morphology.

This possibility can be directly tested using RR Lyraes in the LMC. There are two independent estimates of the average magnitude for field RR Lyrae variables in the LMC: (i) Kinman et al. (1991) found an unreddened average  $\langle B_0 \rangle$  magnitude of  $\langle B_0 \rangle = 19.37 \pm 0.06$ ; if we assume an

average  $\langle (B - V)_0 \rangle$  colour of  $\langle (B - V)_0 \rangle = 0.31$  (Blanco 1992), the average unreddened  $\langle V_0 \rangle$  magnitude is  $\langle V_0 \rangle = 19.06 \pm 0.06$ . (ii) The average  $V$  magnitude of LMC RR Lyrae observed by the MACHO project (Alcock et al. 1996) is  $\langle V \rangle = 19.4$ ; if we assume a value of  $E(B - V) = 0.10$  for the LMC bar (Bessell 1991), we obtain an average unreddened  $\langle V_0 \rangle$  magnitude of  $\langle V_0 \rangle = 19.09 \pm 0.06$ , in good agreement with the result by Kinman et al. These values for the field RR Lyrae in the LMC are to be compared with an average unreddened  $\langle V_0 \rangle$  magnitude of  $\langle V_0 \rangle = 18.94 \pm 0.04$  for cluster variables (Walker 1992). Note that Alcock et al. gives an average metallicity of  $[\text{Fe}/\text{H}] = -1.7 \pm 0.2$  for the field LMC RR Lyrae observed by the MACHO project, quite close to the average value of  $[\text{Fe}/\text{H}] = -1.9$  given by Walker (1992) for the LMC clusters. On the whole, RR Lyrae in the LMC field seem then fainter than cluster ones by  $0.14 \pm 0.08$ , approximately the difference required in the present context. However the difference might be smaller than given by this comparison. In fact, rather large uncertainties exist in the reddening estimates for the LMC, the adopted values depending on the adopted field and on the authors (see Bessell 1991 for a discussion of this point). If we limit ourselves to the variables discovered in the fields around NGC 1466, NGC 1841, NGC 2210, NGC 2257, and Reticulum (summarized by Kinman et al.), and adopt for each field the same reddening considered for the clusters (Walker 1992), field variables are fainter than cluster ones by only  $0.05 \pm 0.02$  mag on average (we give here same weight to all fields, irrespective of the number of variables discovered, to account for the possibility that individual clusters are at a distance from us different than the average field variables). Such a small difference might be entirely attributed to a small difference in the average metallicity (field stars being slightly more metal rich than the clusters).

Alternative tests are provided by the HB of M31, and from data on the Baade-Wesselink method. As to M31, the apparent magnitude of the HB for the globular clusters are in the range  $25.29 < V < 25.66$  (Fusi Pecci et al. 1996), close to the values of  $V = 25.35$  and  $V = 25.45$  obtained by Rich, Mighell & Neill (1996) respectively for the BHB and RHB in the field of G219: from these values the HB of the field does not seem fainter than the HB's of the clusters. However the value given by Fusi Pecci et al. (1996) for G219 is  $V = 25.29$ , this is  $\sim 0.1$  mag brighter than the value of Rich et al. for field stars in the same cluster neighborhood. Of course, it should be reminded that reddening and metallicity for both clusters and field stars are uncertain. It may also be noted that the apparent magnitudes of Rich et al. for the BHB and RHB of M31, coupled with the absolute magnitudes of eqt. (6) and (8), yield estimates of the absolute distance modulus of  $(m - M)_0 = 24.43 \pm 0.16$  and  $24.51 \pm 0.14$  for an interstellar reddening of  $E(B - V) = 0.06$  toward G219 (Fusi Pecci et al. 1996). These values agree well with the value of  $(m - M)_0 = 24.43$  given by Freedman & Madore (1990) from the pre-Hipparcos Cepheids calibration; they are smaller than the value of  $(m - M)_0 = 24.77$  obtained by Feast & Catchpole (1997) using the Hipparcos Cepheid calibration.

As to the Baade-Wesselink method, the absolute magnitudes of RR Lyrae in M5 and M92 (Storm et al. 1994) are indeed about 0.2 mag above the mean relation obtained for

field stars (see Fig. 16 of Clementini et al. 1995); however some of these stars are thought to be evolved objects well above the zero age horizontal branch; on the other side, the variables in M4 (Liu & Janes 1990) fit well the relation for field stars.

On the whole we regard evidences in favour or against a systematic difference between the luminosity of field and cluster HB as controversial; more work is required to settle this point.

We conclude by noting that the adoption of a short distance scale such as that suggested by the present data would have an important impact in various astrophysical problems: e.g. the age of globular clusters would be  $\sim 16$  Gyr, incompatible with an Einstein-de Sitter model for the Universe, unless  $H_0 < 40 \text{ km s Mpc}^{-1}$ . Further work is required in order to determine the absolute magnitude of HB stars.

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